energy sources

Whether the energy needs of a society depend on wood to provide the basic cooking and heating requirements of village life, or on the immensely varied fuel mix of the industrialized nations with their highly complex production and distribution systems, civilization is impossible without an adequate energy supply. In industrialized societies the situation is further complicated by the competition between the use of fossil fuels as an energy source, and their vital role as raw materials for the petrochemical industries, which produce plastics, fertilizers, animal feedstocks, pharmaceuticals, and industrial gases. Thus the so-called energy problem has implications for the whole structure of modern society.

DIMENSIONS OF THE ENERGY PROBLEM

Strictly speaking, no energy problem exists. The basic laws of physics dictate that energy is conserved and can only be changed from one form to another or into matter. FUEL, on the other hand, is the accumulation of matter and therefore represents a store of energy. This energy is released in the form of heat when the fuel is burned in chemical or nuclear reactions, which cannot be reversed to regenerate the original fuel mass (at least not without the injection of more energy than was originally released).

As a consequence, a fuel problem does exist. If the supply of fuel is finite, not only will there be no energy supply when the fuel is exhausted, but also all other processes that depend on it will cease. This will affect not only the obvious energy consumers in the United States and the rest of the industrial West, but even the most primitive societies, where the importance of oil-based fertilizer supplies is growing.

Several factors combine to make the problem an urgent one. World population is steadily increasing, which implies that the demand for energy will also increase, although not necessarily in proportion. Social, economic, and political pressure for economic expansion continues in industrialized countries. This implies an increased energy input. The developing countries are becoming aware that their economic position could be improved by increased energy consumption, and they feel entitled to a larger share of the world's energy resources than they now receive. These pressures require that world energy supply be increased, particularly if the aspirations of some areas are to be met without jeopardizing the living standards of others. Finally, it is now recognized that the supply of the conventional fuels--coal, oil (petroleum), natural gas, uranium, and fuel wood--is limited and insufficient to sustain present rates of development for much longer. Although there may be debate about the exact length of time available before the effects of a worldwide shortage become apparent, there is agreement that such a shortage will occur. It is only a matter of time; in the case of oil, for example, the debate is not about whether, but about when oil production will peak.

RENEWABLE RESOURCES

Renewable energy resources are those which will replenish themselves naturally in a relatively short time and will therefore always be available. They include geothermal energy, hydroelectric power, peat, ocean thermal energy, solar energy, tidal energy, wind power, and fuel wood.

SOLAR RADIATION is a renewable energy source that can be used to produce electricity, by means of SOLAR CELLS, and heat, by means of SOLAR COLLECTORS. SOLAR ENERGY is also indirectly responsible for many other renewable energy sources. The OCEAN CURRENTS and winds (see WINDMILLS AND WINDPOWER) are results of the uneven distribution of solar radiation over the Earth's surface, and the winds in turn produce waves whose energy can be utilized. Solar heating of the upper layers of the ocean generate temperature gradients that can be harnessed to produce electricity (see OCEAN THERMAL ENERGY). The Sun also powers the HYDROLOGIC CYCLE, in which ocean water is evaporated, transported over the continents, and precipitated as rain or snow to form rivers, whose flow energy produces HYDROELECTRIC POWER. Finally, the energy locked in such renewable fuel sources as wood and peat is derived from the Sun by the process of photosynthesis.

Another renewable energy source is GEOTHERMAL ENERGY, which arises through the leakage of heat from the Earth's interior to the surface. Although this happens over the entire surface of the Earth at a very low average rate, leakage is much higher in certain locations. Prime examples are Yellowstone National Park and certain areas of Iceland, Italy, and New Zealand. At these locations, and in general where hot rocks are found at moderate depths, it becomes possible to tap the heat and use it for human purposes.

One or the other of two criteria is essential for the most efficient use of renewable resources: either they must be used at a rate less than their natural rate of renewal or they must periodically be allowed time to build up again.

For example, if the rate of use of geothermal energy is low, it can be a continuous source, but if the rate is increased above that which can be replenished from below, the rocks cool and the energy source temporarily disappears. If left alone, the rocks will heat up and power can again be extracted. Similarly, a water mill operating on a flowing stream will be able to furnish only as much power as the stream can supply; thus there is a natural limit to the amount available at any one time. If, however, the stream is dammed and the water mill put at the outlet of the dam, then it is possible to run the mill for a time at a power level greater than that supplied by the stream. This will cause the level of the water behind the dam to fall, and it must be allowed to rise again before the process can be repeated. Thus, although the total energy available from the stream cannot be controlled, the rate of production, or power, can be modified.

A similar constraint limits the burning of PEAT. Peat represents the accumulation of partly decayed vegetable matter over hundreds or thousands of years, and it is estimated that it accumulates at the remarkably high rate of 3 metric tons per ha (about 1.3 U.S. tons per acre) per year. Extensive exploitation, such as occurs in Ireland and the USSR, results in the depletion of the reserve, which then must be allowed to build up again. The same is true of other fuels, such as wood, which can be exploited for a limited time, after which the forest must be allowed to reestablish itself.

NONRENEWABLE RESOURCES

Nonrenewable resources originate from two processes: (1) photosynthesis, which occurred many millions of years ago, followed by the fossilization of the plant and animal life that resulted, and (2) the formation of the Earth itself. The first gave rise to the fossil fuels--coal, oil (see PETROLEUM), and NATURAL GAS; the second produced the fuels for nuclear energy, such as uranium for fission and lighter elements for fusion. These irreplaceable fuels represent an energy capital that must be invested wisely.

Two aspects are crucial to any evaluation of nonrenewable energy resources: availability and demand. If there is no demand, there is no energy problem, and reserves will last forever. If availability is limited, even the most stringent conservation measures may be inadequate to avoid problems. Both aspects must therefore be examined together. Also essential to an evaluation are the projected rate of increase in demand and the ability of the fuel-producing industries to keep pace.

While perhaps most important in the long run, availability and demand are by no means the only questions associated with nonrenewable energy sources. The case of oil offers an excellent example of the pervasiveness and complexity of energy-supply problems. Oil currently provides between 40 and 50 percent of the world's energy. The situation would be relatively simple if each oil-consuming nation were capable of producing enough to meet its own needs. Complications arise because the nations that consume oil in large amounts do not necessarily produce it in comparable amounts. This situation came forcibly to public attention in the United States during the "oil shocks" of the 1970s, because the nation had passed rapidly from a state of self-sufficiency to one where more than half of its oil supplies were imported.

The "oil shocks" of the 1970s were caused by the establishment of the ORGANIZATION OF PETROLEUM EXPORTING COUNTRIES (OPEC), a cartel of the major oil-producing nations other than Mexico, the United States, and the USSR. In the 1960s these countries began the process of taking control of their own production, most of which had previously been leased to private oil companies. In the early 1970s, OPEC raised prices on crude oil to levels that had severe economic effects on all oil-importing countries. These effects were felt almost immediately, especially in developing countries. Higher prices for petroleum-based fertilizers meant that food-producing costs also rose. The financial resources of the industrialized world, now reduced by the heavy burden of oil costs, meant that markets for the exports of the less-developed countries shrank, while at the same time the prices these countries paid for imported manufactured goods rose, further cutting into development plans. This widening ring of consequences well illustrates the extent to which the economies of modern nations depend on secure supplies of energy.

In the industrialized world the effects of OPEC oil pricing were somewhat less disastrous. In the United States, conservation and economic recession reduced oil imports to less than one-third of the total by the early 1980s, and at the same time created downward pressures on the price of OPEC oil. By 1990, however, over half the oil consumed in the United States again came from imports, and the issue of oil price was perceived once again as a potential economic threat. Large-scale users such as France and Japan have always imported almost all the oil they consume.

The case of coal (see COAL AND COAL MINING) presents a different set of problems. Because coal reserves are

much larger and more widely distributed than petroleum reserves, it seems unlikely that any nation or group of nations could control coal production as OPEC controls the oil supply. Coal is thus clearly capable of furnishing a basic energy supply for far longer than oil or natural gas. In addition, it can supply petrochemical feedstocks, although at greater expense than oil. Proposals currently under large-scale investigation for COAL GASIFICATION and liquefaction (see SYNTHETIC FUELS) would also tend to improve coal's range of usefulness. The heavy use of coal, however, would produce severe pollution problems because coal is a relatively "dirty" fuel. These effects will be felt more strongly in the industrialized nations, because of their greater energy use. Global climate changes might also result from the increased use of coal (see GREENHOUSE EFFECT), with potentially significant effects on agriculture. There is some evidence that the adverse effects of such climate changes would be concentrated in the higher-latitude industrialized nations, whereas the agricultural situation of the less-developed countries, which are located mainly in lower latitudes, might actually improve, thus adding a new source of tension to international affairs.

With nuclear fuels (see NUCLEAR ENERGY; FISSION, NUCLEAR) the demand possibilities are complicated by the possibilities of BREEDER REACTORS, which convert otherwise useless uranium-238 to fissile plutonium-239, or thorium-232 to uranium-233. The world reserves of fissile fuel are thereby increased from only 0.7 percent to all the uranium produced, with almost as much again coming from the thorium that may also be converted. This possibility immensely complicates any calculations of the applicability of nuclear power to future energy supply. Other factors that complicate the issue even more are the toxicity of plutonium, the radioactive waste that is left as a legacy for future generations, and the fact that plutonium is the basic fuel for the atomic bomb, so that the proliferation of breeder reactors increases the possibility of irresponsible production of nuclear weapons and the risk of terrorism. Nevertheless, large commercial breeder reactors have been built outside the United States. Without the breeder reactor, uranium is comparable to oil as a fuel reserve; with it, the situation is eased.

The other nuclear option is fusion (see FUSION ENERGY), the joining together of very light nuclei to make helium. This possibility shows enormous promise, and if present experiments are successful, energy problems could be solved for hundreds or even thousands of years. Each megawatt-year of electrical power generated from this process would apparently require 1.8 kg (3.96 lb) of natural lithium to supply the fuel; and it is estimated that 10 million tons of lithium are available, excluding that dissolved in the oceans. Unfortunately, no fusion reactor has yet produced useful power output; all estimates of fusion power must therefore be viewed with a certain amount of caution. Even if one of the present experimental machines (such as the TOKAMAK) were to work tomorrow, between 10 and 20 years would be needed to make a commercial prototype operational. After this the long process of increasing the number of plants and connecting them to the electrical system would have to be accomplished before fusion could even begin to make a real contribution.

CONVERSION TO NEW SOURCES

The world's long, nearly total dependence on fossil fuels and hydroelectricity ensures that efforts to solve energy problems by switching to alternative sources will have to overcome a great deal of inertia, both economic and psychological. Such sources as solar power, wind power, and synthetic fuels suffer from the serious drawback that few major installations now exist. A large network of plants would have to be constructed, at great cost, before these sources could begin to supply a significant share of the world's energy needs. In addition, these alternatives are handicapped by the engineering problems of converting the energy to a form useful to human beings. For example, although solar energy reaches the top of the atmosphere in amounts 10,000 times greater than all human production of energy, it reaches the Earth's surface at rates of only about 80 to 250 W/sq m, and considerably less on cloudy days. Thus, any large-scale system based on solar-collector panels will be physically huge, causing problems of maintenance and land use. Wind power, wave power, and ocean-thermal-generation sources suffer from similar difficulties. In the long run these technologies may prove to be more efficient on a small scale, providing power and heat for small communities or even single buildings.

Geothermal energy is widely exploited, but the proposals for expanding its utility by drilling into hot rocks have yet to materialize. Extraction of oil from shale (see SHALE, OIL) and TAR SANDS is at present limited to a few commercial sites; programs to convert coal and biomass to liquid fuels on a large scale have so far proved uneconomic. In addition, all power sources, including such supposedly clean ones as solar and wind power, have adverse effects on the environment that must be either accepted or overcome by engineering, generally at a high price. Finally, the inefficiencies of conventional energy converters, such as BATTERIES, ENGINES, and TURBINES, make even more essential the search for new ways of harnessing old and new primary energy sources (see POWER, GENERATION AND TRANSMISSION OF).

Projections of future energy needs and supplies are highly uncertain, but even the more optimistic studies estimate

that only about 25 percent of the world's energy in the year 2000 will be supplied by renewable sources. Most renewable technologies are still in the relatively early stages of development, whereas even that most standard of energy systems, the 1,200-MW fossil-fuel power station, requires 10 years to build. Thus one final factor dominates all decisions that must be made regarding energy planning times: the prospect of oil and gas shortages by the end of this century. The alternative sources may well hold the long-term solution, but in the short term the human race will apparently have to rely on conservation and existing technologies, possibly including the expansion of nuclear power systems.

John T. McMullan

Bibliography: Darmstadter, Joel, et al., How Industrial Societies Use Energy (1977); Frisch, Jean-Roman, ed., Future Stresses for Energy Resources (1986); Halacy, D. S., Jr., Water, Wind and Sun: The Energy Alternatives (1977); Knoepfel, Heinz, Energy 2,000: An Overview of the World's Energy Resources in the Decades to Come (1986); McMullan, John T., et al., Energy Resources and Supply (1976); Mustoe, Julian E., An Atlas of Renewable Energy Resources in the United Kingdom and North America (1984); Schnaiberg, Allan, The Environment: From Surplus to Scarcity (1980); Smil, Vaclav, Energy, Food, Environment: Realities, Myths, Options (1987); Tapp, B.A., and Watkins, J.R., Energy and Mineral Resource Systems (1990); Twidell, Tony, and Weir, Tony, Renewable Energy Resources (1986); United Nations Staff, Report of the Committee on the Development and Utilization of Ne w and Renewable Sources of Energy (1988).